SVERIGES LANTBRUKSUNIVERSITET

A METHOD FOR MEASURING SINGLE-NOZZLE DISTRIBUTIONS INFLUENCED BY OTHER NOZZLES

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ABSTRACT

The purpose of this work was to develop a method with which to measure the spray distribution from a single-nozzle while it is under the influence of other nozzles on a sprayer boom. The nozzle distribution pattern for one nozzle on a seven-nozzle boom was evaluated, using 0.05 M KCl (potassium chloride) solution as marker. Conductivity measurements were made to detect the amount of marked liquid in the distribution along the boom. The spray distribution from the boom was measured on a patternator, with 50 mm channel spacing, and the liquid was collected in 60 graduated cylinders (250 ml). A computer program and an electronic apparatus made it possible to measure the flow rate in each cylinder automatically. To measure the distribution under the boom, the conductivity of the liquid in each cylinder was measured, by taking 100 ml of the liquid to a conductivity cell. Since conductivity is dependent on the temperature of the solution, the temperature of the liquid was measured. Once the actual temperature of the solution was known, it was possible to calculate the corresponding conductivity value at 10°C. As the conductivity of the marker solution was known, it was possible to determine the proportion of marker solution in each cylinder with the ratio $conductivity_{solution}$ / $conductivity_{marker}$. Multiplying this value by the flow rate for each cylinder makes it possible to calculate the flow rate in every cylinder, which ought to give the distribution pattern for the measured nozzle.

The method was checked by adding the individual nozzle distributions, measured with the conductivity method theoretically in a spreadsheet program, to a theoretical distribution below a boom. The theoretical boom distribution was compared with the distribution measured under the boom. Measurements were made with flat fan nozzles of various sizes, for different twist angles and pressures. If the method worked, a modelled distribution ought to agree with a measured one, irrespective of these settings. The results from the conductivity method were compared with the corresponding single-nozzle distribution patterns measured free from the influence of other nozzles. The results showed that the conductivity method worked well irrespective of the parameter settings. Thus the boom distributions modelled on patterns measured with the conductivity method were very similar to the actual distributions measured under the boom. The investigation also showed that this model which simulates a boom distribution based on single-nozzle distribution patterns, measured without the influence of other nozzles were also very similar to the one measured except in the case of small nozzles (Teejet 11001 SS XR). The conductivity method makes it possible to study the interaction phenomenon on a single distribution pattern.

The conductivity method worked well and could be used instead of the conventional method (without influence of other nozzles), when single-nozzle distribution patterns were measured. The distributions measured with the conductivity method are more realistic than the one measured with the conventional method, as the conductivity method includes the interaction information. It could also be used as a tool when investigating the interaction phenomenon, and ascertaining what effect different parameters have on the phenomenon. Use of single-nozzle distribution patterns measured with the conductivity method makes it possible to model a boom distribution as realistically as possible, which could be useful when setting up a boom model with which to calculate the spray distribution on the ground while the vehicle is driving.

CONTENTS

INTRODUCTION

When using pesticides in agriculture, it is important to spray at the right time and to distribute the chemicals at the right place. A deficient dose will not defeat the pest, while an overdose can have a deleterious effect on the crop. The same treatment effect can be achieved with a lower dose if the pesticide can be delivered with greater precision. This would give the farmer better profitability and reduce the burden of chemicals on the ecological system. Experiments with changing of the dose in the plot linearly and using a good application method have shown that it is possible, with some pesticides, to achieve full effect with 30-40% of the present-day recommended pesticide dose (Alness, 1992). Factors that influence the distribution of spray liquid from an agricultural spraying vehicle are nozzle type, nozzle size, vehicle speed, boom movements, pressure, boom height, nozzle wear, weather conditions and drift.

At the Department of Agriculture Engineering of the University of Agricultural Sciences in Uppsala, Sweden, a project is proceeding, concerning spray distribution and its influence on the spray result. This work is a part of a bigger project, that will study the result of a spray work depending on various parameters such as: nozzle type, nozzle sizes, nozzle wear, boom movement, wind, speed of the vehicle, and boom height. The intention is to end up with a model.

Many studies have been made to predict distribution under a boom using single-nozzle distributions. The results of such theoretical distributions are often at variance with the actual distribution under the boom, as the method of modelling used does not include the interaction between nozzles.

This report describes a method with which to measure a single-nozzle distribution influenced by other nozzles on the boom.

LITERATURE REVIEW

Many papers have been written about modelling the spray distribution under a boom using single-nozzles spray patterns. Modelling the spray distribution from a boom has the advantage, compared with patternator measurement, that it is less time consuming. The authors in our review of the literature are not of the same opinion concerning agreement between the measured and the theoretical distributions. Almost every author takes the interaction phenomenon in to consideration, but opinions differ as to whether the effect is negligible or not.

Modelling the distribution under a boom

Authors differ concerning the purpose with the distribution models described in the literature. Some authors and the purpose of their models are described in this section.

Sinfort et al. (1992) used the distribution model in a boom model to predict the distribution resulting from different boom positions. Single-nozzle patterns measured for different tilt angles and heights were used in their model.

Azimi et al. (1985) simulated the distribution under a boom for various parameter settings measured on single nozzles without the influence of other nozzles. The experiment was made to determine the effect of each parameter on the distribution uniformity. The single-nozzle patterns were overlapped in a computer program to obtain a distribution under a boom. The model overlaps the different distributions with different nozzle spacings, in order to find an optimal setting. No data validation of the model was done to ascertain whether the modelled distributions were correlated to a measured one.

Shegwu et al. (1989) used a model to simulate the distribution under a boom according to the parameters boom height, pressure, and tilt angle. The influence of these parameters was simulated using computerized addition of single-nozzle distributions (measured without the influence of other nozzles). The aim of their model was to find an optimal parameter setting for the sprayer.

Mawer & Miller (1989) used a model to study the effect of the tilt angle of a boom on the distribution under the boom, and also to predict the optimal boom height. They used theoretically defined distributions only. Leunda et al. (1990) and Nation (1976) also used theoretical distributions to predict distributions under sprayer booms.

Nation (1976) used four mathematically defined distributions to calculate the effect on distribution evenness of different boom heights and nozzle spacings. He modelled the distributions under a boom with one-half to twice the recommended boom height, assuming that the spray pattern would increase uniformly with increasing boom height. The model was validated by using real nozzles, and Nation found that the agreement was good.

Underwood (1990) modelled the distribution under a boom, using single-nozzle distributions measured at different pressures. He validated the model with distribution measurements on a whole boom. The validation test showed differences between the measured distribution and the modelled one. Patternator measurements of the distribution were recommended.

Novak & Cavaletto (1988) tested wear characteristics of nozzles and compared the results of adding single-nozzle distributions in order to obtain a distribution under a boom.

Different Distribution Models Used

Normal distribution models

The normal distribution model is described with a normal function:

$$\frac{1}{\sqrt{2\pi}} * e^{-\frac{1}{2}x^2} \qquad [1]$$

where:

x = number of tubes or cm distant from the centre of spray pattern

A normal distribution function can be fitted to a single-nozzle distribution if the standard deviation and the total flow rate from the measured nozzle are known. Mawer & Miller (1989) and Leunda et al (1990) incorporated this single-nozzle model in their models. The normal distribution model fitted well with nozzles having 110° top angle, but only reasonably to nozzles with 80° top angle (Mawer & Miller, 1989). The distribution obtained under the boom was often smoother than a measured one.

Beta distribution models

The beta distribution model is used by Mawer (1988) to describe single-nozzle distributions:

$$F(x) = x^{p-1} * (1-x)^{q-1} \quad [2]$$

where:

x = number of tubes or cm distant from centre
p, q = constants describing the shape of the curve (these values had to be found experimentally)

Mawer & Miller (1989) also used this method and claimed that it sometimes fits a single-nozzle distribution better than a normal distribution function.

Triangular distribution models

Mawer (1988) and Nation (1976) used the triangular distribution (see Fig.1) in their boom distribution models. Nation (1976) validated his model with real nozzles and regarded the agreement as good. They said that it justified the use of mathematically defined distributions, since modelled distributions under booms invariably produce slightly better results than those actually measured.

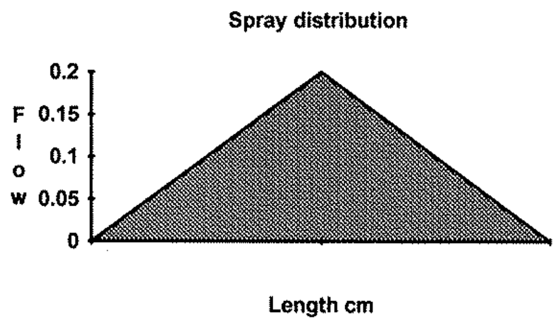


Fig.1. The triangular distribution pattern (after Mawer, 1988).

The flow rate in each tube, according to (Mawer 1988) is:

$$R(i) = x_d(H - x(i) * \cot\frac{\alpha}{2}) * fm \quad x(i) \geq 0 \qquad [3]$$

where:

$R(i)$ = flow rate into tube i
x_d = tube width
H = nozzle height
fm = flow factor
α = nozzle angle
x(i) = distance to centre of tube i

Rectangular distribution models

The definition of a rectangular distribution model is, according to Mawer (1988), that the flow rate is constant over a rectangular shaped area under the nozzle along the spray width. A twist angle on the nozzle will reduce the flow rate at the edges of the spray pattern in the same direction as the boom. This distribution model was also used by Nation (1976).

The spray width is calculated from the nozzle height (H) and the nozzle angle (α). The outer tubes will receive only a fraction of the volume received by the other tubes because of the twist angle (Fig.2). The flow rate (R) in each tube is given by (Mawer, 1988):

$$R(i) = K \qquad 1 \leq i \leq n \qquad [4]$$

$$R(i) = \frac{K(W - nx_d)}{2x_d} \qquad 0 = i = n+1 \qquad [5]$$

where:

K = a constant
W = nozzle spray width
x_d = tube width
n = number of tubes supplied with spray fluid across their whole width

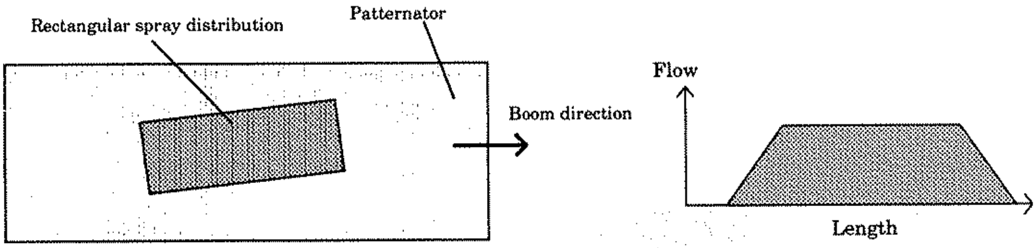


Fig.2 Rectangular distribution on a patternator with a twist angle applied, and the resulting pattern.

Hollow cone distribution models

In this definition of a hollow cone distribution model, Mawer (1988) states that the spray is deposited in a circular pattern (see Fig.3).

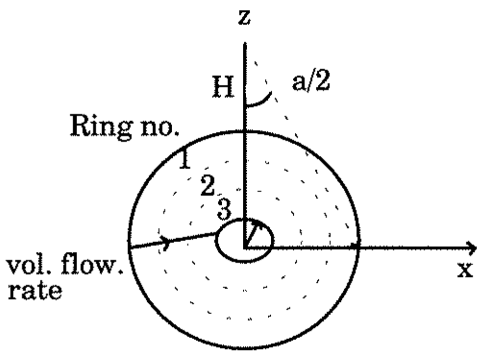


Fig.3 The geometrical shape of a hollow cone nozzle, according to Mawer (1988).

The flow rates are determined as:

$$fc(j) = j \qquad 1 \le j \le n - \frac{r_h}{x_d} \qquad [6]$$

$$fc(j) = 0 \qquad n - \frac{r_h}{x_d} < j \le n \qquad [7]$$

where:

$fc(j)$ = flow rate per unit area in circle number j
r_h = radius of hollow cone centre
x_d = sampling width (tube width)
n = number of circles

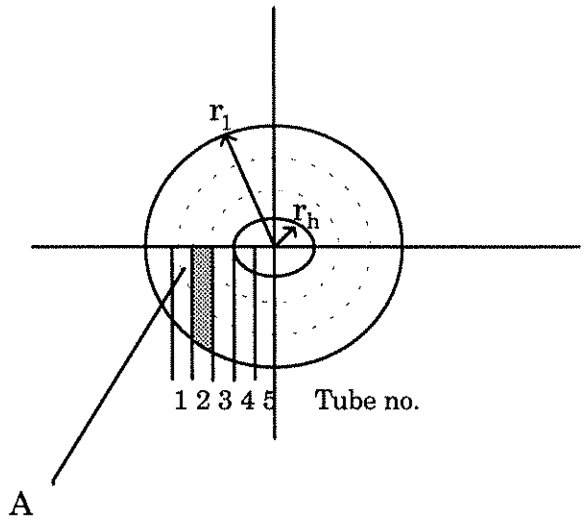


Fig.4 A plan view of the hollow cone distribution according to Mawer (1988).

The area A in Fig.4 is obtained by integrating

$$A = \int_{-4x_d}^{-3x_d} \sqrt{\left(r_1^2 - x^2\right)}dx \qquad [8]$$

Changing to polar coordinates gives:

$$A = r_1^2\left[\tfrac{1}{2}\theta + \tfrac{1}{4}\sin 2\theta\right]_a^b \qquad [9]$$

where:

$$a = \sin^{-1}\frac{-4x_d}{r_1} \qquad \text{and} \qquad b = \sin^{-1}\frac{-3x_d}{r_1}$$

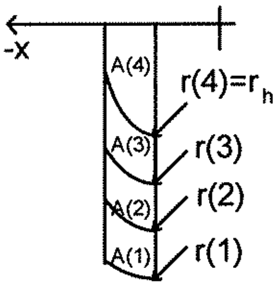


Fig.5 Tube no 4 of Fig.4 according to Mawer 1988.

The total flow in tube no 4, Fig.5 is given by:

R(4) = 2fm(A(1)fc(1) + A(2)fc(2) + A(3)fc(3) + A(4)fc(4)) [10]

where:

fm = flow factor ml m^{-2} s^{-1}
fc = flow rate per unit area

$$A(i) = r(i)^2\left[\tfrac{1}{2}\theta + \tfrac{1}{4}\sin 2\theta\right]_a^b - r(i+1)^2\left[\tfrac{1}{2}\theta + \tfrac{1}{4}\sin 2\theta\right]_a^b$$

Mean distribution models

The construction of mean distribution models is made by calculating the mean distribution from several single-nozzle distribution measurements. Different settings and nozzle type will then be represented by its mean distribution in the boom distribution model. This method was used by Sinfort et al. (1992).

Interaction between nozzles

Mawer (1988) stated that there is an interaction phenomenon between nozzles on a boom, though he assumes this effect to be negligible. Sinfort et al. (1992) describe the interaction phenomenon when the twist angle is zero as collisions between droplets from different nozzles. Disturbances will occur there due to loss of kinetic energy. When the twist angle was greater than zero, they describe the phenomenon as though air movements between the nozzles move the droplets.

CONDUCTIVITY THEORY

Conductivity (conductance)

Conductivity is a well-known phenomenon, fully described in the literature (see for example Saunders, 1966).

If a potential difference is applied between two electrodes in a solution, for instance KCl, a current will pass through the solution. For a given voltage, this current is almost directly proportional to the ion concentration in the solution. Hence it follows that the conductance is almost directly proportional to the concentration. The conductance is defined as:

Conductance

$$C = 1/R = a/l\rho \qquad [11]$$

where:

R = resistance of the solution

ρ = proportionality constant (ohm cm)

$\kappa = 1/\rho$ = the conductivity (specific conductance) of a conductor so that:

$$C = \kappa a/l \quad \Rightarrow \quad \kappa = Cl/a \qquad [12]$$

where:

a = area of the electrode (cm^2)

l = distance between electrodes (cm)

The unit of conductivity (κ) is Ω^{-1} cm^{-1}.

In practice, this way of calculating the conductivity is problematical, because of the complex nature of currents through solutions. A more convenient way is to define the cell constant (K) using a known solution and its table value of the conductivity, calculated as in the formula below:

Conductivity $\kappa = K / R$ siemens / cm or Ω^{-1} cm^{-1} [13]

$K = \frac{\kappa_{table}}{R_{measured}}$ = individual cell constant related to the specific conductivity cell

R = resistance, in ohms

This constant K is specific for the cell and is used together with the cell to calculate the conductivity.

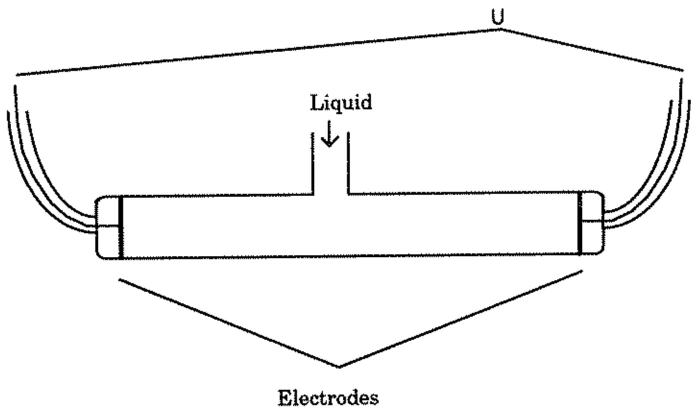


Fig.6. An example of a conductivity cell (according to Saunders, 1966).

When measuring conductivity, it is better to use an alternating current than a direct current, because a direct current will tail off with time, though an electrolysis reaction starts at the electrodes. When an alternating current is used, the ions oscillate at the frequency of the current, and if this is high enough (1-10 kHz) there will be no electrolysis and the current will remain steady.

Conductivity of strong electrolytes such as salt

Solutions of salt in water have the effect that κ is almost proportional to the concentration (c) or that the ratio κ / c is almost constant. The ratio κ / c decreases slightly at higher concentrations. Ions cannot travel as fast at high concentrations as in low concentrations, due to the interaction between ions of opposite charge, moving in the opposite direction (Fig.7).

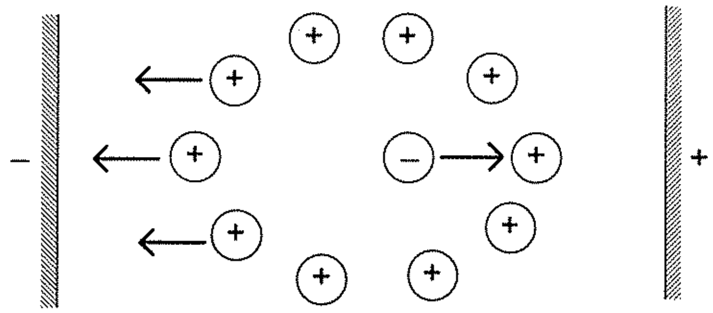


Fig.7. Block diagram showing how ions, of opposite charge interact with each other.

There is also an electrophoretic effect which decreases the ratio κ / c at higher concentrations. This effect is a consequence of the attraction of one or more water molecules to the ions, this attraction occurring because the water molecule is a dipole. Water molecules will be dragged by the ions and these movements will obstruct the ion movement (Fig.8). Since this effect is also greater at higher concentrations, the ratio κ / c decreases at higher concentrations.

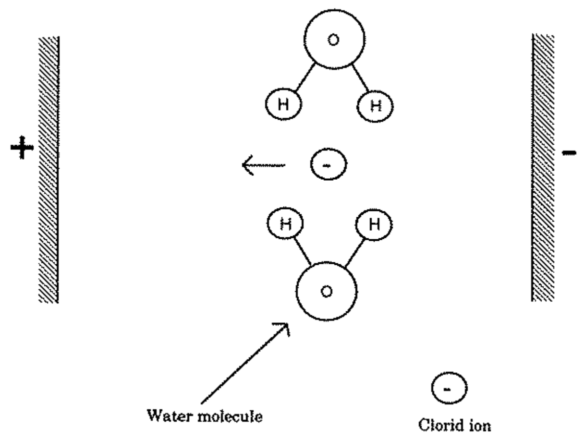


Fig.8. Block diagram of the electrophoretic effect.

If κ / c is plotted against $\sqrt{c}$ the relation will be linear. The amount of current passing through the electrolyte is dependent on the velocities of the ions and the amount of current carried by each ion and of course the number of ions in the solution. The current received is accordingly the sum of ion mobilities in the solution and it is important to have a well defined surrounding, a cell, in which to measure the conductivity. Conductivity is also dependent on the temperature of the solution, a higher temperature giving a higher conductivity. This is due to the greater ion mobility as the temperature of the solution increases. Using KCl solutions, the change in conductivity is about 2.5% per degree around 10°C (Landolt-Börnstein 1960).

HYPOTHESIS

The hypotheses of this work were:

1) If the liquid supplied to a single-nozzle on a boom were marked with a tracer it would be possible to measure this single-nozzle distribution while it interacts with other nozzles, by detecting the proportion of marked liquid in the collecting tubes.

2) By using these single-nozzle distributions measured while interacting with other nozzles, it ought to be possible to device a correct model of a distribution under a boom, by adding the distribution patterns theoretically.

MATERIAL AND METHODS

The aim of this work was to show that it is possible to measure a single-nozzle distribution while it is being influenced by other nozzles on a spray boom. This was possible when the liquid supplied to the measured nozzle was marked with KCl, while all the other nozzles sprayed plain water. The nozzle distribution pattern for one nozzle on a seven-nozzle boom was evaluated using 0.05 M KCl as a marker. The distribution was measured on a patternator with a channel width of 50 mm, and the liquid was collected in 250-ml cylinders. It was possible to detect the amount of marked liquid (%) in each cylinder by measuring the conductivity of the liquid and then calculate the flow rate in each cylinder for the marked nozzle, using the total flow rate data from each cylinder.The method was validated by using single-nozzle distributions measured with the conductivity method. These distributions were added, giving a theoretical distribution below a boom. This theoretical model was then compared with the one actually measured. If the method works, the two distributions will show good agreement, the agreement being independent of all parameter settings. Experiments were also made to show that the other distribution model, using single nozzle distributions measured without the influence of other nozzles could fail in some cases. The conductivity method also enables one to observe what happens with the single-nozzle distribution when nozzles interact with each other. The conductivity method was evaluated by repeating some of the measurements.

Definitions

The method of measuring single-nozzle distributions when not influenced by other nozzles is called the conventional method in this report. The nomenclature used will now be described.

Spray distribution

Spray distribution is defined as the distribution of spray liquid along the boom. The amount of liquid is measured with a resolution depending on the sampling width (channel spacing of the patternator).

Coefficient of variation (CV)

Coefficient of variation (CV) is used to quantify the result of the distribution under the boom. Definition of CV is:

$$CV = \frac{\text{Standard deviation}}{\text{Mean value}} * 100$$

$$CV = \frac{\sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \overline{x})^2}}{\overline{x}} * 100 \qquad [14]$$

where:

n = number of flow rate values, one value from each cylinder
x_i = ith value
$\overline{x}$ = mean

Twist angle

The twist angle is defined according to Fig.9. When measuring Teejet and Lechler nozzles with 10° twist angle, the Quick Teejet cap with fixed twist angle was used.

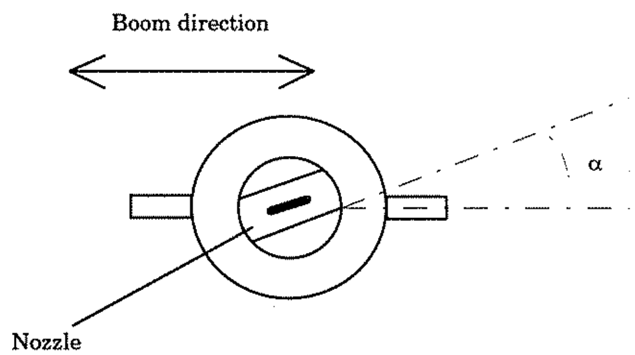


Fig.9. Twist angle definition.

Equipment for measuring the distribution under a boom

Liquid support

Water was used as spray liquid. The water was stored in a large cistern that supplied a piston-diaphragm pump (Comet P 48, Italy). A pressure equalizer was placed after the pump to reduce pressure variations and an adjustable valve made it possible to regulate the pressure. The water was distributed to the nozzles via a pressure tube that split up into six different lines of the same length giving the same pressure fall for all nozzles. A manometer measured the pressure continuously, near one of the nozzles.

The marked liquid (water and KCl) was distributed in parallel through a pressurised tank, via a pressure tube to the nozzle. The tank was pressurized with air, regulated by a throttle. Pressure was measured continuously by a manometer near the nozzle. Fig.10 shows the liquid support system.

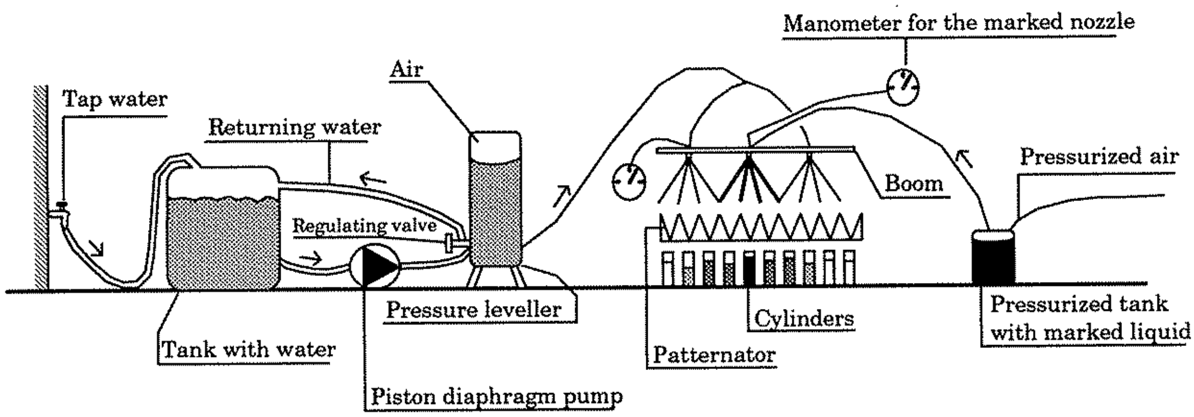


Fig.10. Block diagram of the liquid support system. Only three nozzles are shown, though seven nozzles were used in the experiment.

The boom

The boom was made of a quadratic aluminium profile, on which seven flat fan nozzles were mounted at 50-cm intervals along the boom, using the Quick Teejet nozzle assembly (Spraying System, U.S.A) (Fig.11). The boom was mounted at right angles to the channels in such a way that the height could be adjusted. In this test the boom was mounted 50 cm above the patternator. To adjust for the different twist angles (5° or 10°) Quick Teejet caps with fixed twist angle or Quick Teejet caps with a round aperture were used. The Quick Teejet caps with fixed twist angle could not be used for Hardi nozzles. When the twist angles were set, it was more important to have the same angle between the measurements than to have the exact angle. Therefore when Quick Teejet caps with fixed twist angle were not used, a simple key was used to give the same angle (5° or 10°) every time. The anti-drip device in the nozzle was removed to avoid an extra pressure fall.

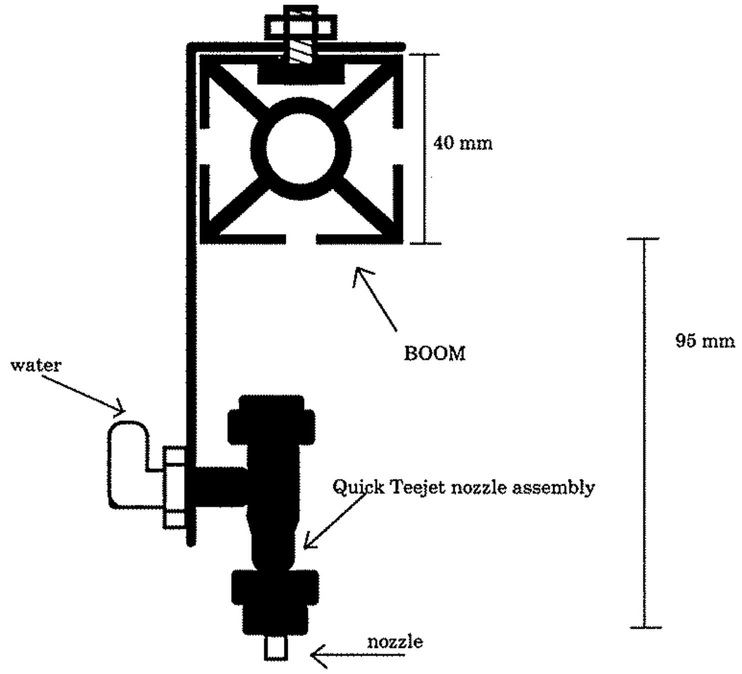


Fig.11. The boom (aluminium profile) and nozzle assembly mounted on the boom.

The patternator

The patternator (Fig.12) consisted of a table with 80 channels, each channel was 50 mm wide and 1.2 m long. The channel dividers were made of aluminium and the channels of galvanized metal. To keep the table horizontal, and yet maintain liquid output the channels were deeper at the front (0.25 m) than at the rear (0.22 m). This difference in height gave a slope of about 1.4°. The liquid was collected in 80 graduated cylinders (250 ml) at the lower end of the table. An electronic measuring device measured the time it took to fill the cylinders. A computer program on a PC controlled and collected data from the cylinders. It also printed a graph on the screen and presents the CV value. All cylinders were fixed to a bar, making it possible either to place them under the channels to collect the liquid or to empty them. It was also possible to move the cylinders away from the liquid flow to lead some of the collected liquid to the conductivity cell.

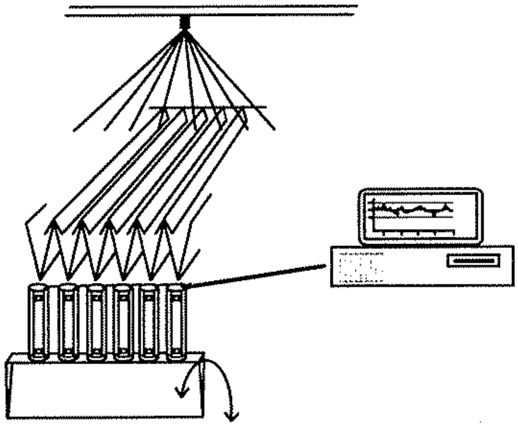


Fig.12. Block diagram of the patternator and the collecting equipment used in the experiment.

Electronics used to measure liquid flow

An electronic system was used to measure the liquid flow. An electronic card was inserted in each cylinder (Fig.13), which enabled a computer to measure the time taken for the liquid surface to pass between two points. As the system compares the conductivity between air and liquid, it can detect whether the liquid surface had passed or not. When the liquid surface passes the first gap in the card, the program starts a timer, and when it passes the second gap, the program stops the timer. If one knows the time and the volume (238 ml), one can calculate the flow rate. A computer program (devised by Agroinvent AB, Sweden) in a PC controls and collects data from the cylinders. Information from one run was stored in a specific file named by the controller. The program prints a graph on the screen according to the flow rate in each cylinder and presents the CV value. It was also possible to have the graph printed on a printer. A print-out from the program is shown in Appendix I. The data were then inserted into a spreadsheet program (Microsoft Excel 4.0) for further calculations.

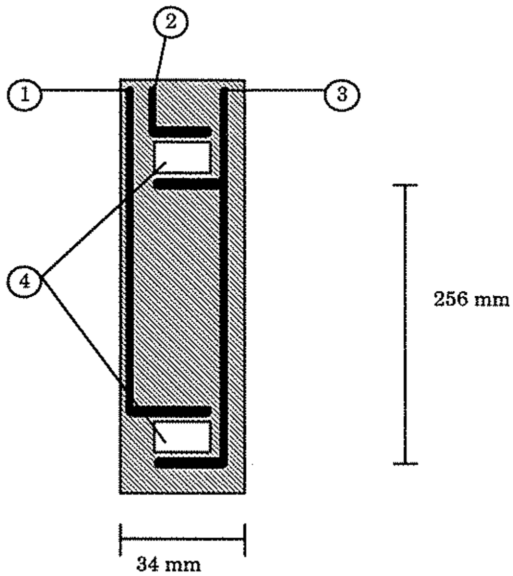


Fig.13. The electronic card inserted into each cylinder, used to measure the time taken for the liquid surface to pass between the two gaps (4). The computer uses copper lines (1) and (3) to detect when the liquid surface passes the first gap when it switches on the timer. The timer stops when the liquid reaches the upper gap, detected by copper lines (2) and (3). The volume between the gaps is 238 ml when the card is inserted into the cylinder. The copper lines were coated with plastic except for the part over and under the gaps.

Equipment used to measure conductivity

The conductivity in this experiment was measured in a conductivity cell. The temperature was measured in every fifth cylinder with an electronic instrument.

Conductivity cell

Conductivity was measured in a conductivity cell (constructed at the Department). It was made of plexiglass with electrodes of stainless steel. Fig.14 shows the construction of the cell. Its volume is about 90 ml. To maintain constant cell volume between measurements, the cell was filled with liquid up to the hole at the top. Liquid was fed from the graduated cylinders to the conductivity cell with a 100 ml syringe. To avoid any influence between measurements, cell and syringe were rinsed between measurements.

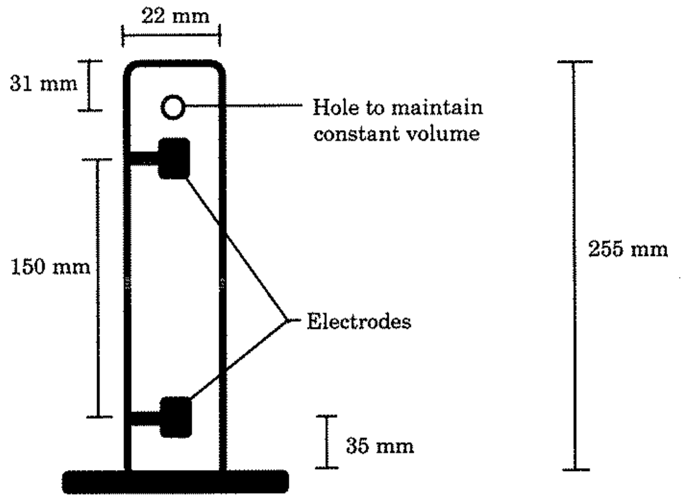


Fig.14. Conductivity measuring cell. The cylinder was made of plexiglass and the electrodes of stainless steel.

Electronics

To measure the conductivity in a solution is the same as to measure the resistance in the liquid between two electrodes. At the Department of Agricultural Engineering of the Swedish University of Agricultural Sciences an electronic instrument was constructed to measure conductivity. Fig.15 is a block diagram of the components. The instrument works as follows. A pulse generator gives a sinus wave of 1 volt over the electrodes in the conductivity cell. After the conductivity cell, an amplifier amplifies the current received, and the signal then passes a low-pass filter, which reduces the noise. A full-wave rectifier converts the alternating voltage to a direct voltage which be measured with a digital multimeter. This conductivity instrument has a linear output up to ~1.8 V. To check the instrument's output, different resistances, instead of solutions, were used in the instrument. The instrument used together with the conductivity cell made it possible to use a ~ 0.065 M KCl solution. To leave a margin, 0.05 M KCl solution was used during the measurements.

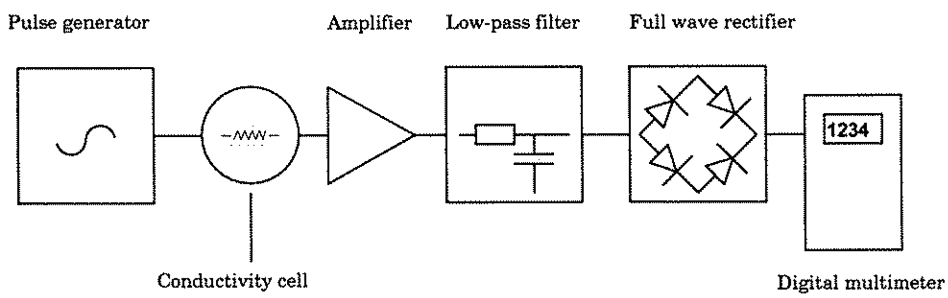


Fig.15. Block diagram of the instrument used to measure conductivity.

The instrument expressed output in volts. The cell constant was determined by measuring a solution of known conductivity and use formula [13]. The conductivity values were then obtained by multiplying the cell constant by the given output from the instrument.

The cell constant of the conductivity cell was: $0.003896\ \Omega^{-1}\ cm^{-1}\ V^{-1}$

Temperature

The temperature was measured with an electronic instrument (FLUKE). A copper-aluminium element was used.

Measurements

Experimental plan

The measurements made are summarized in Table 1. To verify the repeatability of the conductivity method, four nozzles were measured twice (nos. 3,4).

Single-nozzles were measured with both the conductivity method and the conventional method. The distributions were compared to ascertain what happens to the distribution pattern when the nozzle is influenced by other nozzles (numbers 2, 3, 4 and 5).

Distributions measured with the conductivity and conventional methods were compared by adding the theoretical distribution to a boom distribution model and comparing them with the distribution measured under the boom (numbers 1,2,5,6 and 7).

Table 1. Experimental plan. All measurements were made at 50 cm boomheight and 50 cm nozzle spacing.

NOZZLE	Pressure	Twist angle	Number of nozzles examined		
			METHOD		
			Conventional	Conductivity	NO
Teejet 11001 XR VS	1.5 bar	10°	-------------	7	1
	3.5 bar	5°	7	7	2
	3.5 bar	10°	2	2	3
Teejet 11004 XR VS	1.5 bar	5°	2	2	4
	3.5 bar	10°	7	7	5
Hardi 4110-20 plastic	3.5 bar	10°	-------------	7	6
Lechler LU 120-04 S	3.5 bar	10°	-------------	7	7

Measurement of single-nozzle distributions without interaction

All nozzles used in the test were individually numbered from one to seven. The nozzles were then fixed to the boom in rising order. When the single-nozzle distribution was measured, liquid was supplied to the nozzle by a tube that could be transferred between the nozzles. This ensured that the nozzles remained in the same place over the patternator for every measurement. Since each nozzle was fixed to the same place on the boom both times, we could compare the modelled distribution with the measured one without being concerned about possible errors in channel spacing, and pressure drops caused by different tube lengths to the nozzles, and differences in twist angle between different positions on the boom wich would cause differences on the influence between the nozzles.

Before the measurements were made, all nozzles were mounted on the boom, and boom height and twist angle were checked for each nozzle. The pump was then started and the pressure regulated. Once the pressure had stabilized the cylinders were put under the channels, and the timer was started and the glasses were filled.

Measurement of single-nozzle distribution with interaction

Before the distribution was measured, boom height and twist angle were set and the tube with marked liquid was fixed to one of the nozzles. A solution of 0.05 M. KCl was mixed (67.1 g KCl and 18 l water) and fed into a tank which was then pressurized with air. Once the pressure was applied and adjusted to the correct level, the nozzles were allowed to spray for about 3 min to stabilize the mixture between water and the marked liquid in the channels. Thereafter the computer started to measure the distribution along the boom. When measuring was completed the cylinders were removed from the liquid flow, and the pressure was turned off.

Conductivity and the temperature of the water and marker solution were measured, to make it possible to calculate the amount of marked liquid in the cylinders. About 100 ml was fed from each cylinder to the conductivity cell to be measured. Temperature was measured in every fifth cylinder. Conductivity was measured from the outer edge of the single-nozzle distribution pattern, and the conductivity would then be higher in the next cylinder. Between the measurement of each cylinder, the conductivity cell and the syringe were rinsed to avoid interference between cylinders. When half of the pattern had been measured, and the position was under the nozzle, the conductivity cell and the syringe were rinsed very carefully. Thereafter the measurements started from the other outer edge of the single-nozzle distribution pattern, moving towards the centre.

When all the cylinders had been measured, they were emptied and rinsed. The patternator was also rinsed to avoid interference with the next measurement caused by marked liquid that might possibly have remained in the channels. Then the tube with marked liquid was moved to the next nozzle to be measured and the height was checked, as the boom had been touched. Thereafter the same measuring procedure was repeated for the next nozzle, until all seven nozzles had been measured with the conductivity method.

As the tap water kept at about 10°C and the temperature in the room was also about 10°C, any temperature compensations needed were small. Before the measurements were started, the tap water was allowed to flow a while until the water temperature had stabilized.

Calculations

Calculations were done using a spreadsheet program (Microsoft Excel 4.0) on a PC. The calculations that had to be made, were the flow rate for the single-nozzle distributions when nozzles interact. The flow rate calculations for the distribution under a boom were made in the computer program on the measuring PC.

To calculate the single-nozzle distribution when nozzles interact, the amount of marked liquid (%) in each cylinder had to be calculated, by taking the ratio between the concentration in the cylinder and the concentration of the marker solution. To count the concentration for a certain conductivity value, a 2nd order polynome was adapted to table values of conductivity and concentration at different temperatures (Landolt Börnstein 1960). The polynome was adapted to the conductivity values for concentrations 0.01-0.1 M and temperatures between 8° and 12°C (see Fig.16). The relationship is not linear between conductivity and the concentration. If a straight line was adapted, an error of about 3-4% was made. If instead a 2nd order polynome was adapted, the error was about 0.5%.

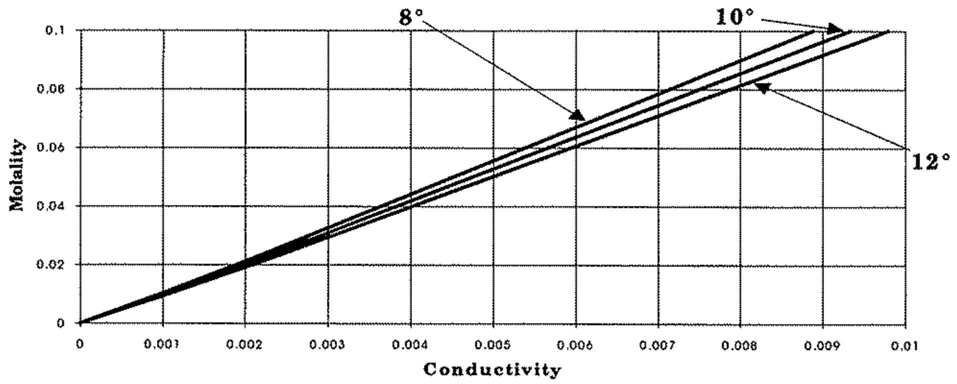


Fig.16. Connection between conductivity and concentration at three different temperatures (after Landolt - Börnstein, 1960).

The equation adapted to the table values is:

$$c = \frac{9.84\kappa + 93.8\kappa^2}{1 - 0.0245(t - 10)} \qquad [15]$$

where:

c = concentration mol / l
$\kappa = \kappa$(solution)-$\kappa(H_2O)$ is the conductivity in S cm^{-1}
t = temperature in °C

This equation gives an error of about 0.5%, compared with the table values, in a temperature interval of 10-12°C.

Since the conductivity value of the water was greater than zero it had to be measured and subtracted from the conductivity value of the solution.

To calculate the amount (%) of marked liquid in each cylinder the concentration of the marked liquid had to be determined. By dividing the concentration of the mixed solution by that of the marker solution, the proportion of the marker liquid in the cylinder was obtained.

RESULTS

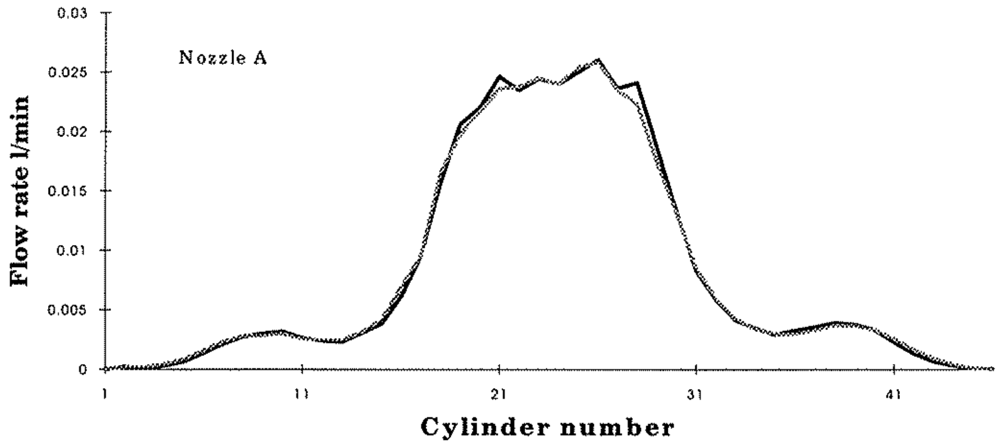
When single-nozzles were measured with interaction, the conductivity method was used, and when were measured without interaction the conventional method was used.

Table 2. CV value and mean flow rate from the modelled distributions

Nozzle	Pressure	Twist angle	Measured		With interaction		Without interaction	
			Mean	CV %	Mean	CV %	Mean	CV %
Teejet -01	1.5	10	0.028	14.7	0.027	14.9	-------------	-------
	3.5	5	0.042	20.0	0.041	22.0	0.041	12.7
	3.5	10	-------------	-------	-------------	-------	-------------	-------
Teejet -04	1.5	5	-------------	-------	-------------	-------	-------------	-------
	3.5	10	0.0165	7.0	0.162	7.2	0.165	6.7
Hardi -04	3.5	10	0.164	5.4	0.161	6.2	-------------	-------
Lechler -04	3.5	10	0.167	6.8	0.161	6.9	-------------	-------

Repeatability of the conductivity method

The repeatability of the conductivity method was good for the nozzle types measured and the pressure and twist angle measured. The distribution patterns are shown in Figs. 17 and 18.



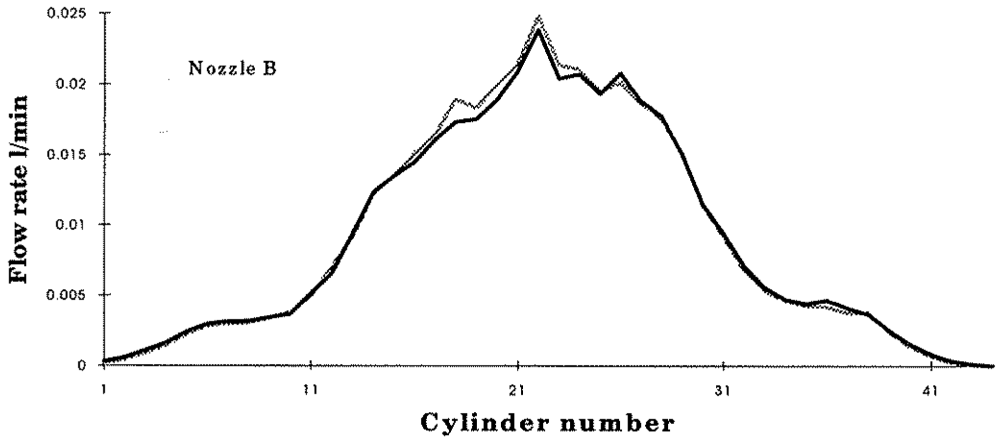


Fig.17. Repeatability for single-nozzles with interaction measured with the conductivity method, measured with two nozzles of the type Teejet 01 XR VS, at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

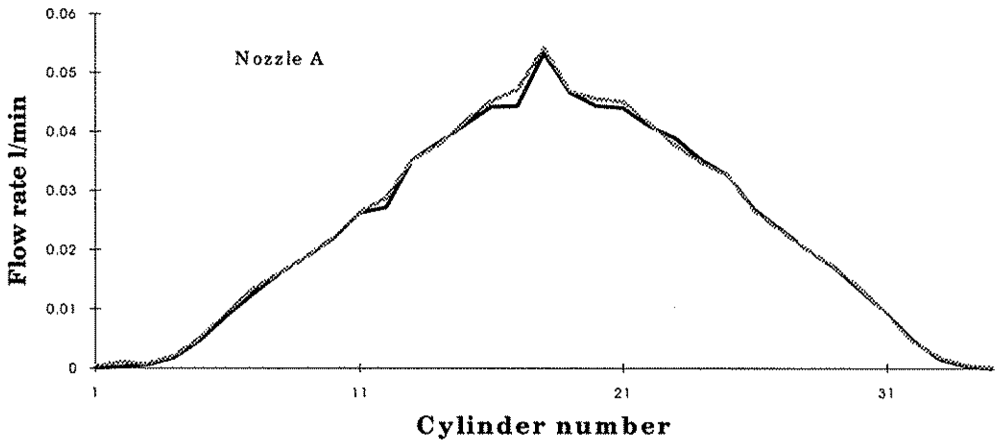


Fig.18.a. Repeatability for single-nozzles with interaction measured with the conductivity method, measured with two nozzles of the type Teejet 11004 XR VS (A), at 50 cm boomheight, pressure 1.5 bar and 5° twist angle.

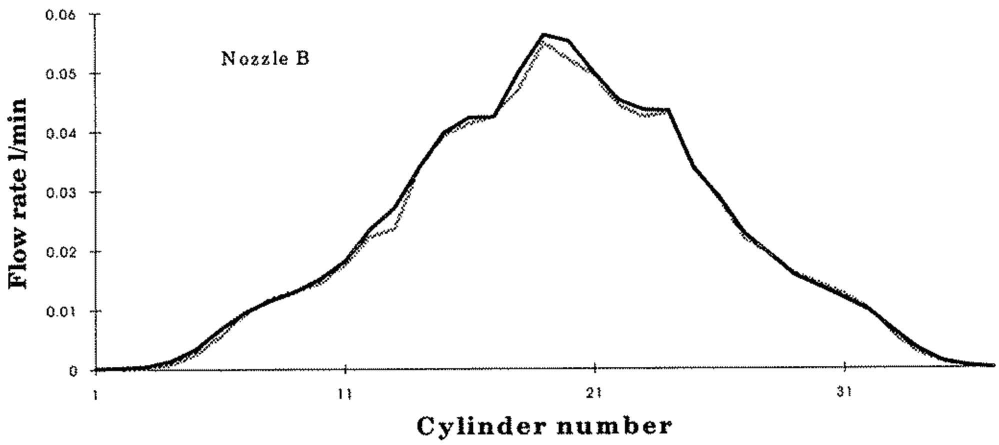


Fig.18.b. Repeatability for single-nozzles with interaction measured with the conductivity method, measured with two nozzles of the type Teejet 11004 XR VS (B), at 50 cm boomheight, pressure 1.5 bar and 5° twist angle.

Single-nozzle distribution measured with conductivity method compared with distributions measured with conventional method

Figs.19-22 show the patterns, and the differences between patterns, measured with the two methods. The measurements showed greater differences between the distribution patterns measured with the two methods for the small nozzles (Teejet 11001) than for the larger ones (Teejet 11004).

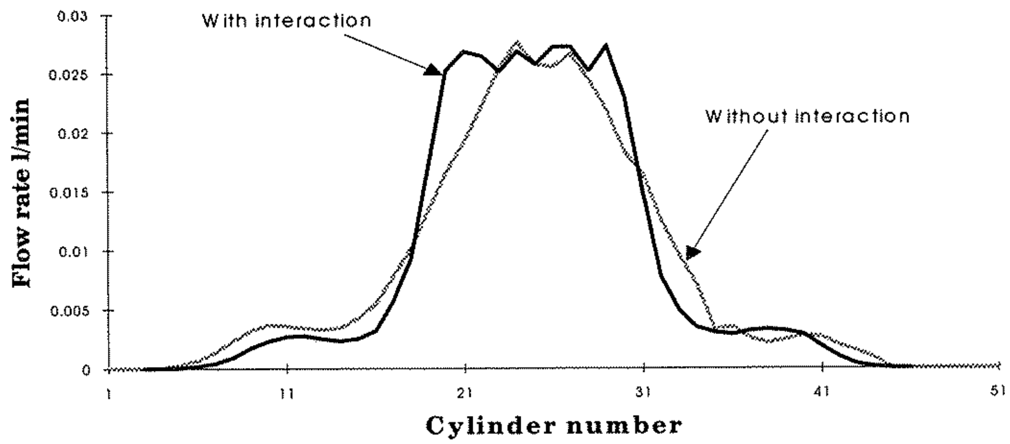


Fig.19. Distribution patterns measured with and without interaction method. Nozzle Teejet 11001 XR VS at 50 cm boomheight, pressure 3.5 bar and 5° twist angle, was used.

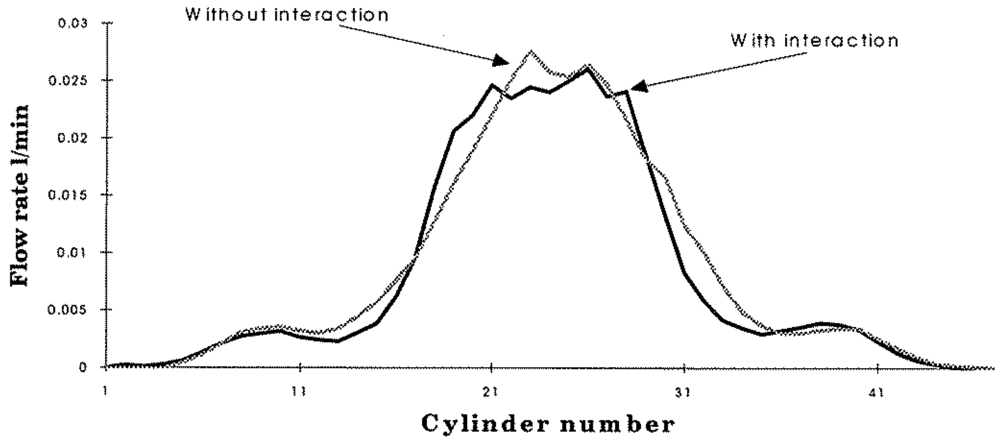


Fig.20. Distribution patterns measured with and without interaction. Nozzle Teejet 11001 XR VS at 50 cm boomheight, pressure 3.5 bar and 10° twist angle, was used.

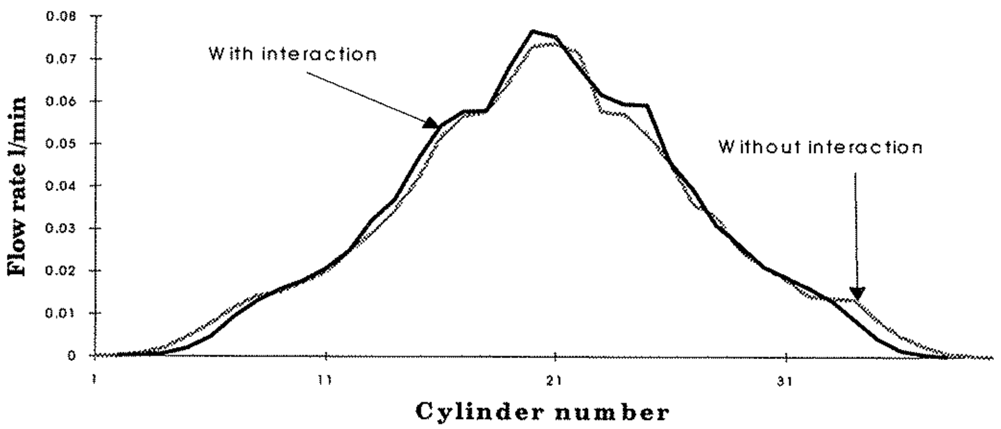


Fig.21. Distribution patterns measured with and without interaction. Nozzle Teejet 11004 XR VS at 50 cm boomheight, pressure 1.5 bar and 5° twist angle, was used.

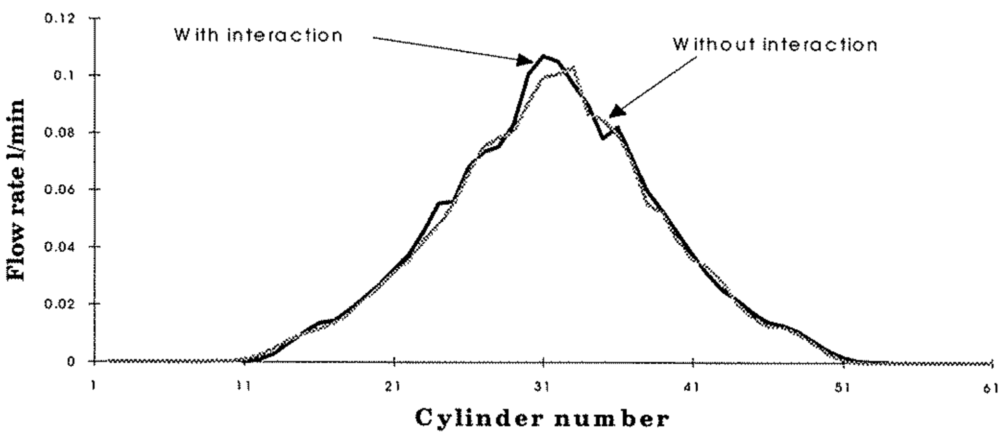


Fig.22. Distribution patterns measured with and without interaction. Nozzle Teejet 11004 XR VS at 50 cm boomheight, pressure 3.5 bar and 10° twist angle, was used.

Two methods modelling distribution under a boom

Figs.23-26 show the results of the comparison between the boom distribution models and the measured distribution. For the larger nozzles, (-04) the agreement between the measured distribution and the modelled was good, both for the conventional method and for the conductivity method. The distribution model formed from distributions from the small nozzles (Teejet 11001) measured with the conductivity method agreed with the measured distribution, whereas the model formed from distributions measured with the conventional method did not fit the measured distribution (Fig.23).

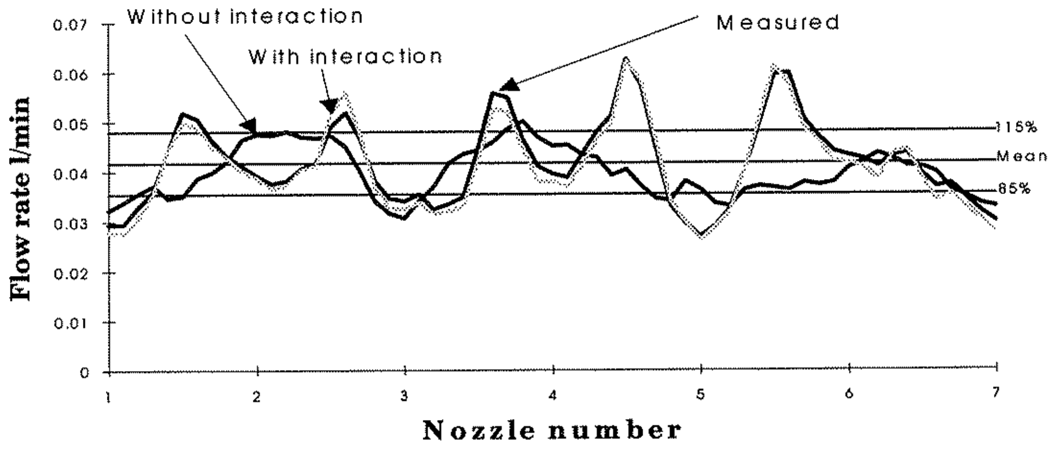


Fig.23. Distribution models compared with measured distribution. Nozzle Teejet 11001 XR VS at 50 cm boomheight, pressure 3.5 bar and 5° twist angle.

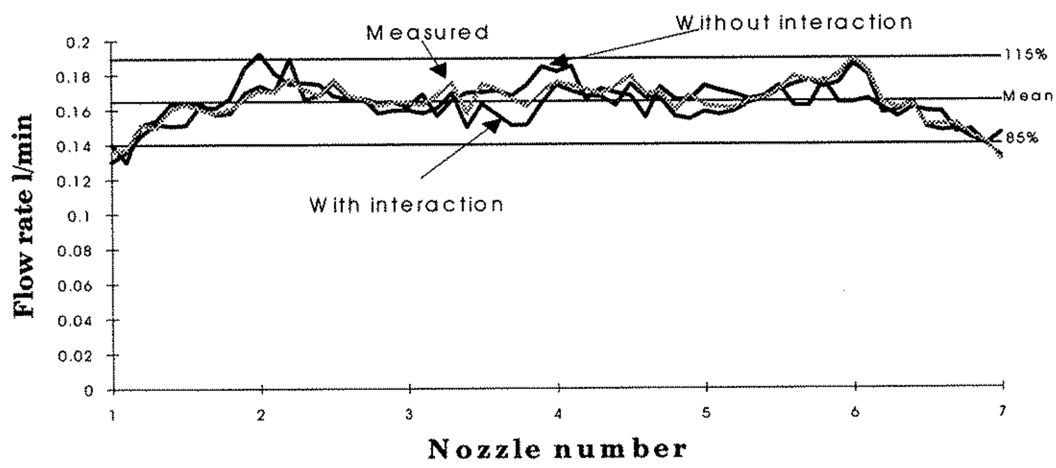


Fig.24. Distribution models compared with measured distribution. Nozzle Teejet 11004 XR VS at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

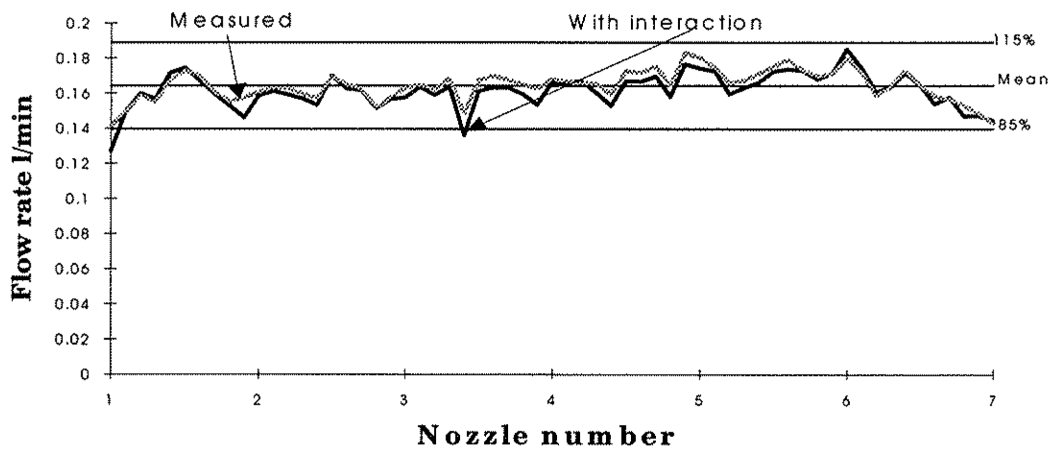


Fig.25. Distribution model compared with measured distribution. Nozzle Hardi 4110-20 at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

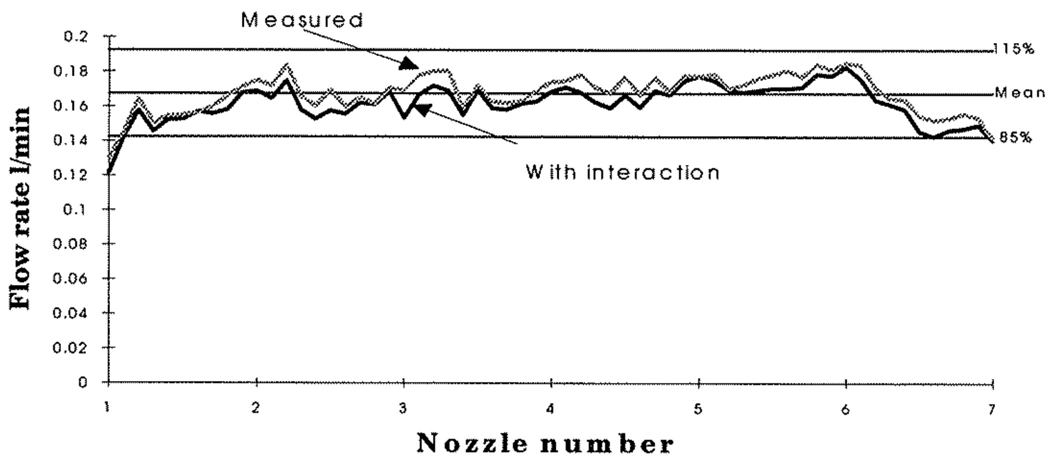


Fig.26. Distribution model compared with measured distribution. Nozzle Lechler LU 120-04 S at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

Variation in nozzle distributions for nozzles of same type measured with conductivity method

Figs.27-30 show the differences between distributions measured with the conductivity method for nozzles of the same type. Fig.27 and Fig.28 show the distributions for the same nozzles (Teejet 11001) but under different operating conditions. Observe the differences in spread between the patterns for the small (-01) and the large nozzles (-04).

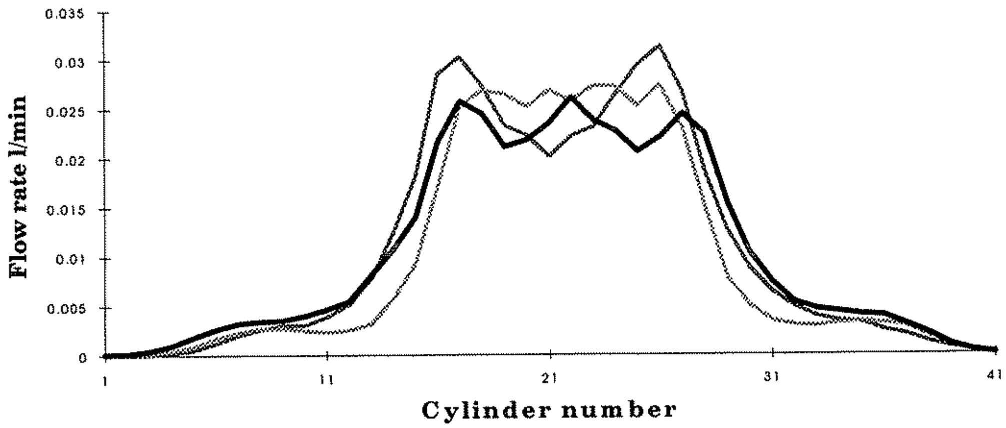


Fig.27. Variation between patterns for different nozzles of type Teejet 11001 XR VS. Measured at 50 cm boomheight, pressure 3.5 bar and 5° twist angle.

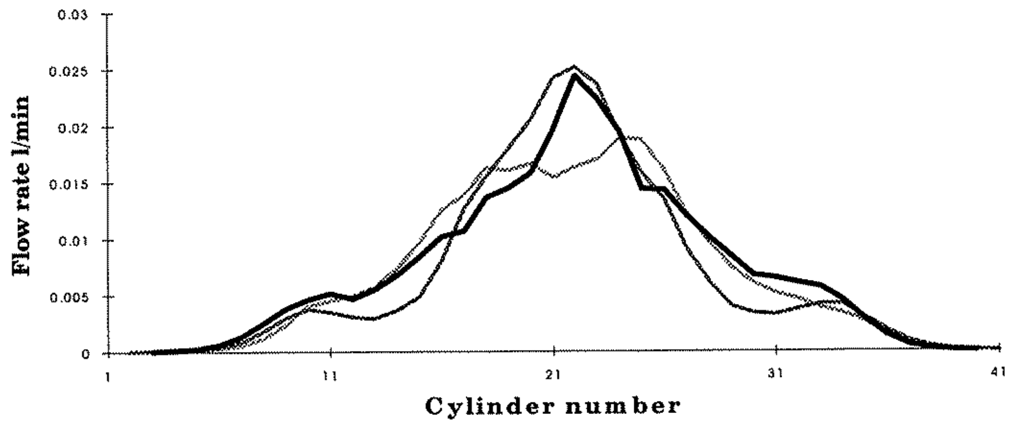


Fig.28. Variation between patterns for different nozzles of type Teejet 11001 XR VS. Measured at 50 cm boomheight, pressure 1.5 bar and 10° twist angle

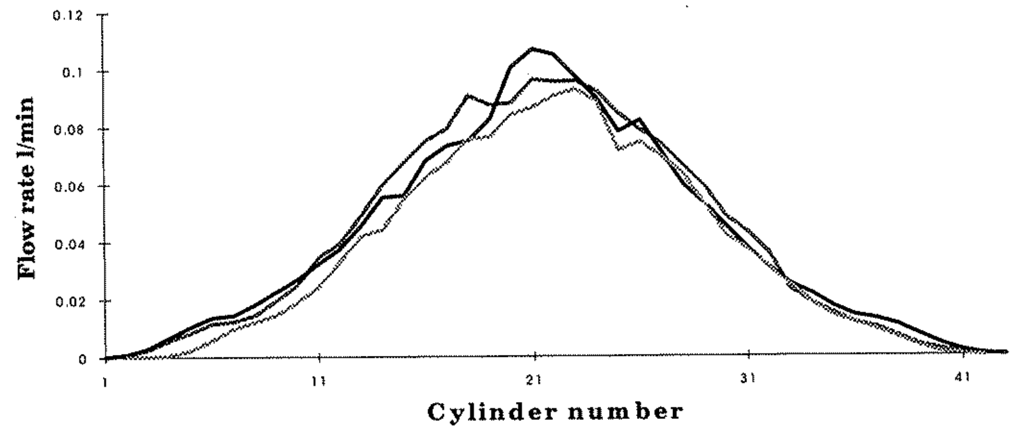


Fig.29. Variation between patterns for different nozzles of type Teejet 11004 XR VS. Measured at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

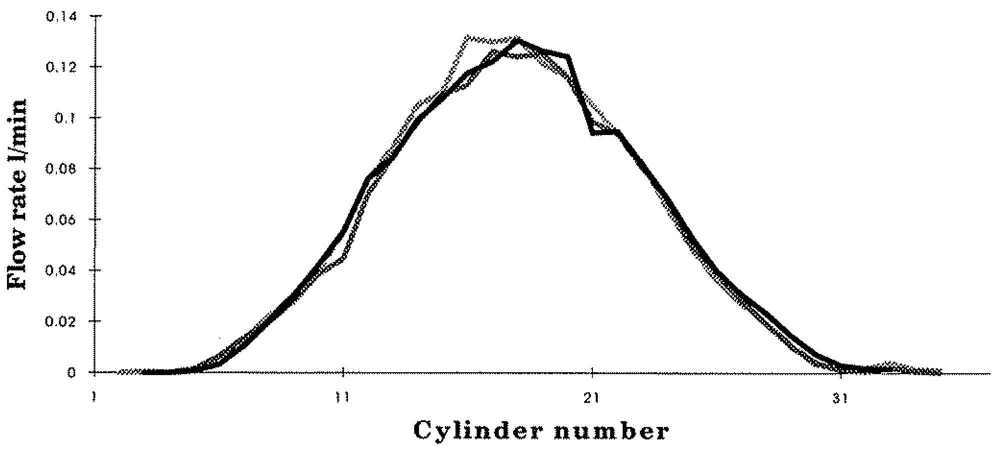


Fig.30. Variation between patterns for different nozzles of type Hardi 4110-20. Measured at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

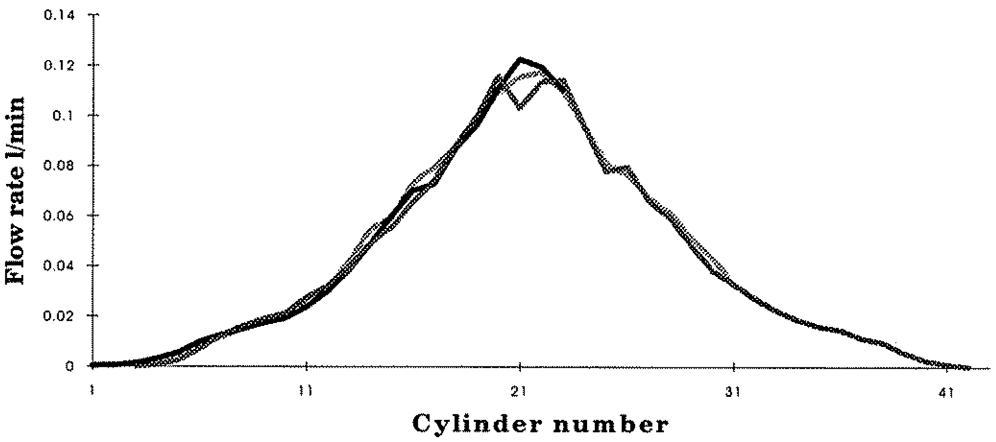


Fig.31. Variation between patterns for different nozzles of type Lechler Lu 120-04 S. Measured at 50 cm boomheight, pressure 3.5 bar and 10° twist angle.

DISCUSSION

Measurement of single-nozzle distributions whilst influenced by other nozzles, and using the conductivity method, established the hypothesis stated in the beginning of this report. It is possible to measure the distribution from a single-nozzle while it interacts with other nozzles on a boom. It was also found possible to devise a correct model of a distribution under a boom, using single-nozzle distributions measured with the conductivity method while the nozzle interacts with other nozzles. The agreement between the modelled distributions and the measured ones was good for both small and large nozzles. When a distribution was modelled using single-nozzle distributions, and measured without interaction the agreement was good for the large nozzles (Teejet 11004 XR VS), but there was a considerable difference between the distributions (measured and modelled) when small nozzles (Teejet 11001 XR VS) were used. This difference probably depends on that the single nozzle distributions used did not contain the interaction information. It can be concluded that when we model a distribution under a boom, using nozzle distributions, measured with interaction, we will invariably reach a good agreement with the measured distribution. It is also possible to reach a good agreement using single-nozzle distributions, measured in the conventional way in some cases, but not in others. The conductivity method should be a useful tool for investigating the interaction phenomenon, or when distribution data are to be measured for use in a boom distribution model.

Measuring the conductivity of liquids is a well known and reliable method described in the literature. Numerous measurements have been made to determine the conductivity of KCl solutions at different concentrations and temperatures. It is possible to study the behaviour of conductivity at different concentrations and temperatures in the literature (for example Landolt-Börnstein, 1960). The differences that occurred between the repetitions made with the conductivity method in the present study were probably due to errors made when the parameters were set between measurement occasions. It was observed that the conductivity electronic equipment had to have a stable temperature before measuring, or else values would drift. To avoid this drift the electronic conductivity equipment was never shut off. In the measurement of single-nozzle distribution with interaction, two manometers were used one for the marked nozzle, the other for the other nozzles. A problem concerning the manometers is that they had to be checked (calibrated) against each other, as the tubes to the manometers could have different lengths and would cause different pressure losses. The largest error was possibly when the pressures were set and it would be advantages if the interaction between the marked nozzle and the other nozzles did not behave in the same way in the two measurements. The differences that occurred between measurements were not caused by some unknown factor in the conductivity method, but the differences that did occur were small and repeatability was good.

Measurement of single-nozzle distributions while they interact with other nozzles could also have been done by methods other than conductivity. For instance fluorometry using a fluorescent tracer and spectrophotometry using some kind of stain as tracer. The conductivity method was chosen because it is a stabile method and does not break down with time due to some chemical reaction. The fluorescent tracer has the disadvantage that it decomposes in daylight. The conductivity method is insensitive to pollution in the water in the way that the spectrophotometry method is. Another important reason is that it is relatively easy to integrate the conductivity method in to an automated system for the measurement of spray distributions.

When comparing results from an analysis of the spray pattern, one should bear in mind that the resulting distribution is dependent on the channel spacing on the patternator.

The use of theoretically devised or mean value distributions in a distribution model may deviate too much from real distributions. The problem with these types of distributions is that they do not take the spread in distribution between nozzles into consideration. Instead, the same distribution is used for every nozzle on the modelled boom. When this type of model is validated with a distribution from a boom with real nozzles, the modelled CV is often less than the real one (Leunda, 1990). The way a distribution should be modelled is to measure many nozzles (interacting with the conductivity method) of one type and then calculate the mean value distribution, and the variation between patterns at each measured point. These data should then be used when modelling a distribution under a boom, and using a random number generator to calculate the flow rate at each measuring point using the mean value and variation at that point. If this technique is used, one can obtain different distributions that can still be represented by the type of nozzle used.

When comparing single-nozzle distributions from the same nozzle under comparable conditions, measured with both methods, it was found that the difference between the patterns was greater for small nozzles (-01) than for larger nozzles (-04). One interpretation could be that the main cause of the interaction phenomenon is air flow moving the droplets rather than droplets hitting each other, as there are more small droplets in the spray when small nozzles are used. If the droplets had hit each other and lost their kinetic energy, the differences would also have been greater for the larger nozzles. This phenomenon requires further study to ascertain the cause. Another possibility is that the influence is dependent on the characteristics of the surrounding nozzles. The interaction distribution from one nozzle would accordingly differ if the surrounding nozzles were changed to other individuals of nozzles. One should still bear in mind that these measurements measure static behaviour, and the distribution patterns are only a bit more true than the one measured one the conventional way.

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Personal Communication

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Appendix I

TESTRESULTAT / SPRAY SCANNER PLUS-92 / (C) AGROINVENT AB / RHG HANNOVER

Datum : 15.01.1993

Anl. zu Bericht: 123

Prüfert : Patrik Enfält

Kontrollort : Uppsala

Duesenfabrikat : Teejet

Kennwort : A:\EXJOBB.SSP

Duesentyp : 11004 ss xr

Druck [bar]: 3.5

Bemerkungen: Konduktivitet

Duesendurchsatz ca [l/min] = 1.65

Variationskoeffizient [%] = 5.3